Chapter 8

Water Allocation Systems

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Additional information is available at the end of the chapter

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1. Introduction

Water resources are shared by many people who use the water for a variety of purposes. Water allocation systems serve to equitably apportion water resources among users; protect existing water users from having their supplies diminished by new users; govern the sharing of limited water during droughts when supplies are inadequate to meet all needs; and facilitate efficient water use. Effective water allocation becomes particularly important as demands exceed reliable supplies. As water demands increase with population and economic growth, water allocation systems must be expanded and refined.

The institutional framework for water resources development and management involves a hierarchy of water allocation systems. Water resources are allocated between nations by treaties and other agreements. In the United States (U.S.), water is allocated between states through interstate compacts. Water is shared by regional water authorities, municipal utility districts, cities, private companies, irrigation districts, farmers, and individual domestic water users through water rights systems. Water supply entities service their customers in accordance with contracts and other commitments. Federal water development agencies provide reservoir storage capacity for nonfederal sponsors.

This chapter begins with a general overview of institutional systems for allocating the water flowing and/or stored in rivers, lakes, and aquifers to diverse types of water use and numerous water users. The chapter then focuses on the Texas experience in implementing water allocation systems, including both accomplishments and issues still remaining to be resolved. The state of Texas in the United States serves as a case study that illustrates concepts and strategies that are relevant throughout the world.

With a population of 26 million people and land area of 696,000 km^2, Texas is a large state with diverse geography, economy, climate, hydrology, and water management practices. Texas has a rich heritage of implementing water allocation strategies as a central thrust of its water resources planning, development, and management. The Rio Grande is shared with Mexico, and several major river basins are shared with neighboring states in the U.S. Thousands of government agencies, cities, private companies, and citizens hold rights to use the waters of the state. Water allocation involves multiple overlapping institutional mechanisms. The state has progressed significantly in recent years in improving its water allocation systems. Further refinements continue to be a priority policy emphasis.

The Water Rights Analysis Package (WRAP) modeling system simulates the water allocation systems described in this chapter. WRAP is routinely applied in Texas in regional and statewide planning studies, administration of the water rights permit system, and other water management activities. WRAP is generalized for application anyplace in the world.

2. Water allocation mechanisms

People in various nations, regions, and local communities have developed their own sets of institutions and practices governing the sharing of water. These water allocation systems have evolved historically and continue to change. Hierarchies of water allocation systems in the U.S. and many other countries generally have the following components or features.

- The waters of international rivers and aquifers are allocated between nations based on international law, customs, treaties, and agreements.
- In the U.S., waters of interstate river basins are allocated between states based on compacts negotiated by the states and approved by the federal government.
- Certain rights are reserved for military installations and other government owned lands and facilities.
- A legally established priority system based generally on variations of the riparian or prior appropriation doctrines guides the allocation of the surface water flowing in streams and stored in reservoirs.
- A separate system of laws and customs guides the allocation of water resources in ground water aquifers.
- An administrative system that grants, limits, and modifies water rights and enforces the allocation of water resources may or may not include formal issuance of written permits to water right holders.
- Water users and water management entities implement various contracts and other formal agreements.
- Sharing of water resources may be governed by cultural traditions and informal agreements that evolve historically over many years.

Water allocation mechanisms typically vary greatly between ground-water and surface-water. From a water law perspective, ground and surface water are usually treated as separate resources. The extent to which the important hydrologic and water management interconnections are recognized varies between geographical regions.

The institutional mechanisms of water allocation are typically viewed from policy, legal, economic, and social perspectives. However, hydrologic science and engineering are also important aspects of developing and maintaining water allocation systems [1, 2, 3].

2.1. Allocation of the waters of international rivers and aquifers

Principles and rules of international water law are found in treaties, international custom, general principals of law, and writings of international institutions [4, 5, 6]. Two hundred and sixty-one international river basins, each encompassing portions of two or more nations, cover about 45 percent of the world's land area excluding Antarctica [7]. Little progress has been made in developing effective water allocation systems in many of these international river basins. Water allocation is even more difficult for groundwater aquifers shared by two or more countries.

Effective joint multiple-nation water management will be a major determinant in achieving stability, peace, and prosperity in many regions of the world in the 21st century [8, 9, 10, 11, 12]. Examples of the many regions with dramatic potential for either cooperation or conflict include the following. The Jordan River shared by Israel, Jordan, Syria, and the Palestinians is a small stream with remarkably great historical and political importance. Shared groundwater is also an important issue this region. The Euphrates and Tigris Rivers flow from Turkey through Syria, Iraq, and Iran. Most of the flow of the Euphrates and Tigris Rivers originate in their upper watersheds in Turkey and is controlled by a system of major dams in Turkey. The Ganges and Brahmaputra River Basins in Nepal, China, India, Bhutan, and Bangladesh, with a history of centuries of water conflicts, contained an estimated 400 million people in 2000 living at an impoverished standard of living. In the Southern African Region encompassing Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe, every major river is shared by two or more nations. Population growth and economic development are resulting in intensified demands on limited water resources with a long history of controversy.

2.2. Water rights in the United States

A water right is the legal privilege to store, regulate, and/or divert water for beneficial use. Water law is the creation, allocation, and administration of water rights. Institutions and customs for executing water rights play key roles in water management in various regions throughout the world. The following discussion is from a U.S. perspective but has broader applicability in other countries as well.

Books on water rights/law range from a concise book entitled *Water Law in a Nutshell* [13] to a massive eight volume collection [14] first published in 1967 and again as a revised updated edition in 1991 with the individual volumes continuing to be periodically updated and expanded at different times. The American Society of Civil Engineers has published guidelines for developing water right rules and regulations [15, 16, 17]. Other books focus on water rights in particular regions of the world other than the U.S. [18, 19, 20, 21].

Each state in the U.S. has developed its own set of laws, institutions, and practices governing water rights. These systems have evolved historically and continue to change. States in the western and eastern halves of the U.S. have generally adopted different approaches to water rights due largely to the western states having much drier climates. Water allocation and accounting systems tend to be more rigorous in regions where demands approach or exceed supplies. The experience of the state of Texas discussed in this chapter illustrates key aspects of developing and administering water right systems. Regions of Texas are representative of both western and eastern states.

Surface water in streams and lakes is viewed in the U.S. as a renewable resource owned by the state and used by the public. Groundwater is typically viewed as the property of the owners of the land overlying the aquifers. Water rights for groundwater aquifers are very different than for surface water streams and lakes. Although water rights are established primarily at the state level, federal laws govern water rights for military installations, other federal lands such as national parks, and Indian reservations.

For river basins encompassing portions of multiple states, water is allocated between states based on interstate compacts developed by the states, approved by the U.S. Congress, and administered by interstate compact commissions. Disputes may arise in implementing interstate compacts, particularly during droughts. Disputes are settled by the U.S. Supreme Court if compact commissions cannot work out disagreements between the states through negotiation. A major objective of compact commissions is to avoid lawsuits, but disputes in the western states in particular often reach the litigation stage. Various states have experienced lengthy and costly water allocation disputes settled through the U.S. Supreme Court [22]. Shared management of interstate groundwater aquifers and associated development of water allocation mechanisms have not progressed to nearly the extent as surface water.

2.2.1. Surface water rights

Legal rights to the use of stream flow are generally based on two alternative doctrines, riparian and prior appropriation. The basic concept of the riparian doctrine is that water rights are incidental to the ownership of land adjacent to a stream. The prior appropriation doctrine is based on the concept of protecting senior water users from having their supplies diminished by newcomers developing water supplies later in time. In a prior appropriation system, water rights are not inherent in land ownership, and priorities are established based on dates that water is appropriated.

The doctrine of riparian rights common in the eastern U.S. is based on English common law. Under the strictest interpretation of the riparian doctrine, the owner of riparian land adjacent to a stream is entitled to receive the full natural flow of the stream without change in quantity or quality. Since a strict interpretation imposes impractical constraints on water use, the riparian doctrine is normally interpreted to allow riparian land owners to divert reasonable amounts of stream flow for beneficial purposes. Varying definitions of *reasonable amounts* complicate water allocation.

The doctrine of prior appropriation is associated with settling the American West. As settlers moved from the eastern states to the West in the 1800's, farmers and ranchers claimed land, and miners claimed gold and other minerals. Likewise, water was appropriated by the first to arrive and claim the resources for beneficial use. In developing their farms and communities, people needed protection from having their water supplies diminished with later population growth and economic development.

Most of the western states have established permit systems in which a state agency issues permits to water right holders specifying amounts and conditions of water use. Riparian and/or appropriative rights may be incorporated into the original development of the permit system, with additional new permits being issued based on prior appropriation. With growing demands on limited water resources, permit systems will likely continue to be developed in the eastern states, which have more abundant stream flow, similar to those already in place in the drier western states.

Surface water rights in the eight driest western states (Nevada, Arizona, Utah, Idaho, Montana, Wyoming, Colorado, and New Mexico) are based purely on the prior appropriation doctrine. Alaska is also a prior appropriation state though somewhat different. Ten western states with hybrid systems merging riparian and appropriative rights into permit systems include California, Oregon, Washington, Texas, Oklahoma, Kansas, Nebraska, South Dakota, North Dakota, and Mississippi. Hawaii has a unique hybrid system. Water rights in 30 eastern states are based primarily on the riparian doctrine [23].

2.2.2. Groundwater rights

The rights and obligations for groundwater use are generally tied to two legal principles: property ownership and shared ownership of a common public resource. A variety of state approaches to groundwater rights has evolved from these concepts. State groundwater law is based on mixtures of the following doctrines.

Absolute Ownership Doctrine: Landowners own the groundwater under their land and may drill wells and pump as much water as they wish. Texas and several other states have historically adhered to this doctrine but are slowly changing.

Reasonable Use Doctrine: Landowners own groundwater, but their pumping is limited to reasonable use which has been defined in a variety of ways. This doctrine is common in the eastern states.

Correlative Rights Doctrine: In times of shortage, groundwater is shared by overlying landowners in proportion to the amount of land they own. This extension of the reasonable use rule is primarily associated with California.

Prior Appropriation Doctrine: Groundwater is allocated similarly to surface water with priorities assigned based on the dates that users first appropriate the water for beneficial use. This doctrine is common in the western states.

Permit Systems: Systems in which state agencies issue permits specifying the amounts and conditions of water use have been adopted in 33 of the 50 states. The other doctrines may be reflected in the water rights documented by the permits. Texas is among the 17 states that have no state-wide groundwater permit program.

Some states divide groundwater into categories with different water right rules applied to each classification. Percolating groundwater may be legally differentiated from underground streams with definable flow paths. Underground streams are sometimes treated as being similar to surface streams.

The issue of impacts of groundwater pumping on surface stream flow has been addressed to varying extents in different states. In some states, groundwater is classified as either tributary or nontributary. Tributary groundwater hydrologically contributes to surface stream flow. Nontributary groundwater does not. Water right rules and management strategies for tributary groundwater are based on protecting surface water rights.

3. Water allocation systems in Texas

Texas is a large state located in the south-central U.S. that is representative of both the drier western and wetter eastern states from various perspectives including climate. Mean annual precipitation varies from 20 cm at the city of El Paso in arid west Texas to over 140 cm in the humid eastern extreme of the state. Texas actually provides two case studies since water allocation in the Lower Rio Grande Valley has distinct differences from the remainder of the state. Water rights are a major consideration in river basin management statewide. Allocation of ground water is very different than allocation of surface water.

Water resources development and management in Texas is governed largely by the need to be prepared for extended droughts. The hydrologically most severe drought of record began gradually in 1951 and ended in 1957 with one of the largest floods on record. Droughts in the 1910's and 1930's were also extended multiple-year dry periods over large areas of Texas and neighboring states. The drought that occurred during 1995-1996 was much more economically costly than the earlier droughts due to the population and economic growth that had occurred. In terms of annual precipitation, for more than half of the land area of Texas, 2011 was the driest calendar year since the beginning of official observed precipitation records in 1895. The remainder of the state was also very dry during 2011. Severe drought conditions are continuing during 2012 throughout Texas and other states in the U.S.

3.1. Water resources planning, development, and management

The Texas Water Development Board (TWDB) in partnership with 16 regional planning groups outline future water resources needs and challenges in the 2012 State Water Plan, which is presented in a multiple volume report entitled *Water for Texas 2012* [24]. Water demands are projected to increase about 22 percent between 2010 and 2060. Available water supplies with existing infrastructure and current institutional arrangements will decrease about 10 percent during this period due to reservoir sedimentation and depletion of groundwater aquifers. Environmental flow requirements and ecosystem preservation are major concerns as well as meeting municipal, industrial, and agricultural water needs. The regional planning groups have identified several hundred water supply projects with an estimated cost of over $50 billion to address intensifying water needs. The TWDB predicts that annual losses from not meeting water supply needs could result in a reduction in income of approximately $12 billion annually if current drought conditions approach the drought of record, and as much as $116 billion annually by 2060 [24].

The map of Texas in Figure 1 shows the larger rivers and cities of the state. The state encompasses a land area of 696,000 km^2 divided into 15 major river basins and eight coastal basins located along the Gulf of Mexico between the lower reaches of the major river basins. The 1990 population of 17.0 million people increased to 25.7 million in 2011 and is projected by the Texas Water Development Board [24] to increase to 46.3 million by 2060. Fifty-eight percent of Texans live in the state's three largest metropolitan areas: the Dallas/Fort Worth Metroplex in the upper Trinity River Basin, greater Houston area in the San Jacinto River Basin, and city of San Antonio in the San Antonio River Basin. With a 2011 population of 6.5 million people, the Dallas/Fort Worth (DFW) Metroplex is the largest metropolitan area in the southern U.S. and the fastest growing metropolitan area in the U.S. With a 2011 population of 6.1 million, the city Houston and adjacent smaller cities is also one of the largest and fastest growing metropolitan areas in the U.S. San Antonio is the third largest city in Texas with a population of 2.2 million people. Conversely, several of the major river basins of the state have extremely low population densities. Water management practices are very diverse throughout the state.

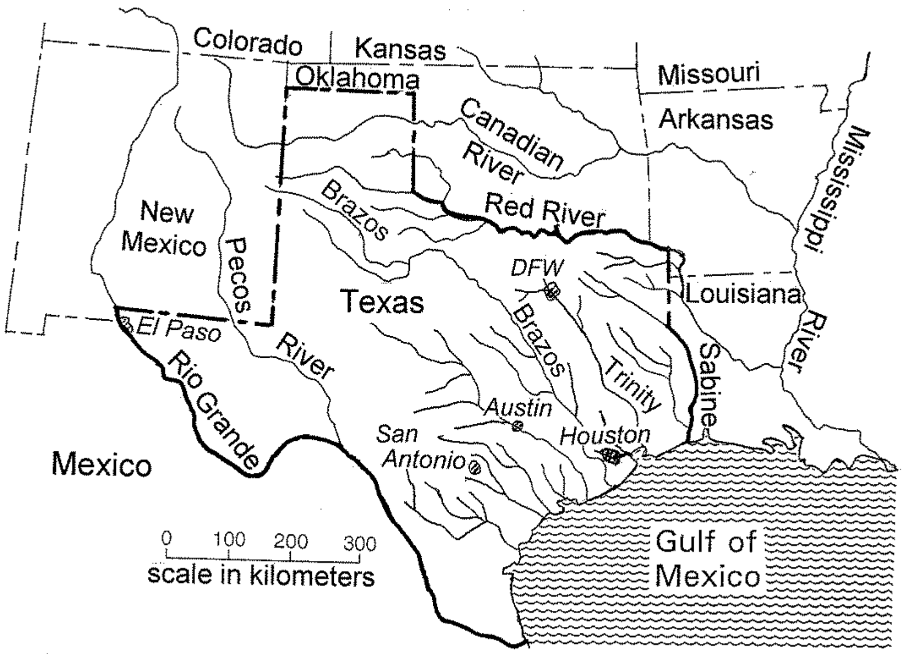

Figure 1. Map of Texas showing major rivers, largest cities, and neighboring states

Total diversions of 22 billion m^3/year from streams, reservoirs, and aquifers statewide in 2010 was for agricultural irrigation (56%), municipal use (27%), industrial use (15%), and livestock (2%). Currently, about half of the water supplied is from groundwater aquifers, and the other half is from surface streams and reservoirs. However, problems caused by decades of groundwater pumping rates significantly exceeding recharge rates in various regions of the state are resulting in major shifts toward greater reliance on surface water.

The naturalized flow volumes during each of the 864 months of 1940-2011 at a gauging station on the Brazos River near Houston are plotted in Fig. 2 to illustrate the tremendous variability that characterizes stream flows throughout Texas. A highly variable resource is allocated to numerous water users. Long-term mean flows may be relatively large, but most of the flow occurs during infrequent flood events. The water management community must deal with droughts with durations ranging from several months to several years. Dams with large storage volumes are essential in order to develop dependable water supplies. The river flows plotted in Fig. 2 are generated by the modeling system described later in this chapter by adjusting gauged flows to represent natural conditions without human water resources development and use.

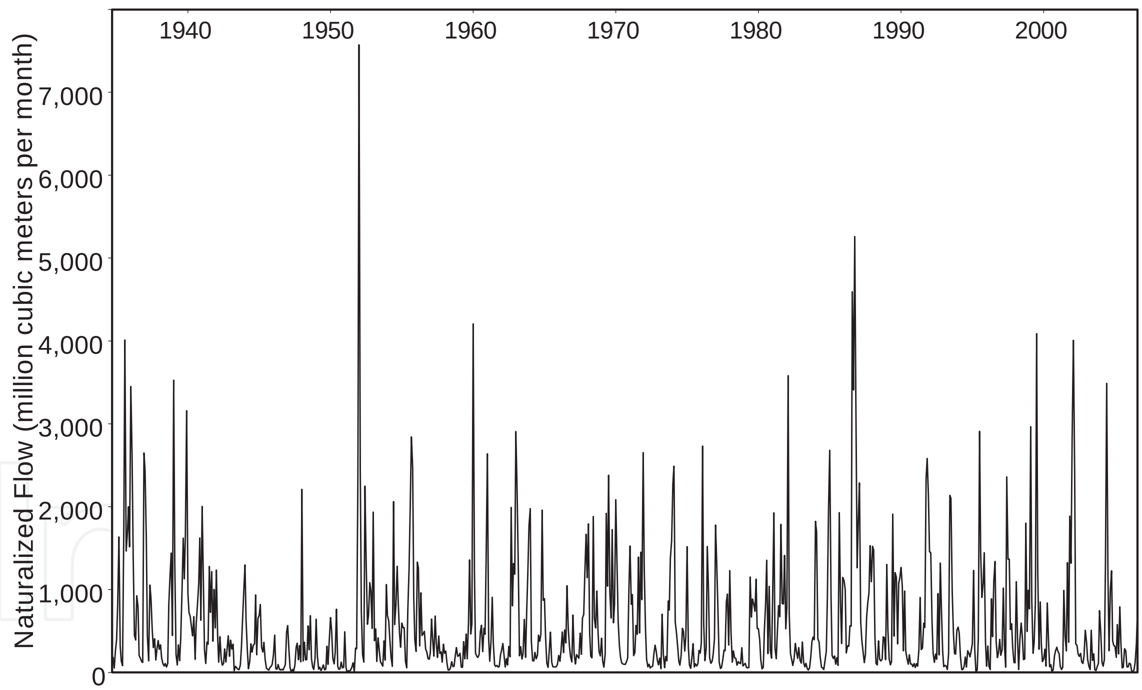

Figure 2. Monthly naturalized flows of the Brazos River illustrating variability

Conservation and flood control storage capacities totaling 50 and 23 billion m^3 are provided by 211 major reservoirs with individual capacities of 6.2 million m^3 or greater. Although there are several thousand smaller reservoirs, the 211 major reservoirs account for over 95% of the storage capacity in the state. Texoma on the Red River and International Amistad on the Rio Grande are the largest reservoirs with capacities of 6.6 and 6.3 billion m^3. The 22 hy-

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droelectric plants in the state are components of electric utility systems dominated by thermal plants. Reservoir releases through hydropower turbines are almost always incidental to downstream water supply needs.

Federal involvement in developing the state's water resources includes 32 U.S. Army Corps of Engineers (USACE) reservoirs in eight river basins and two International Boundary and Water Commission (IBWC) reservoirs on the Rio Grande that account for about 40% and 90% of the conservation and flood control, respectively, storage capacity of the 211 major reservoirs. The U.S. Bureau of Reclamation constructed three reservoirs that are now owned by local entities. River authorities and cities have contracted for the water supply storage capacity of the USACE reservoirs. All costs allocated to water supply are reimbursed by the nonfederal sponsors, who also hold the water right permits. The USACE is responsible for flood control operations.

Nineteen river authorities are responsible for development and management of the water resources of all or portions of major river basins. River authorities construct and operate their own reservoir projects and contract for storage capacity in federal reservoirs. Numerous municipal utility districts and irrigation districts also play key roles in supplying water from rivers and reservoirs. Groundwater conservation districts facilitate groundwater management.

Some type of water rights system has been administered statewide by a centralized agency since 1913, but that agency has changed over time. The Board of Water Engineers was established in 1913; reorganized as the Texas Water Commission (TWC) in 1962; and renamed the Texas Water Rights Commission in 1965 with non-water rights functions being transferred to the Texas Water Development Board (TWDB), which had been previously created in 1957. In 1977, the Texas Department of Water Resources (TDWR) was created by combining the Water Rights Commission, TWDB, and Water Quality Board. In 1985, the TDWR was dissolved, and the TWC and TWDB became separate agencies. The Texas Natural Resource Conservation Commission (TNRCC) was created in 1993 by merging the TWC and Texas Air Quality Board. The TNRCC was renamed the Texas Commission on Environmental Quality (TCEQ) in September 2002. The TCEQ is now responsible for administering the many regulatory programs of the state including the water rights system.

The TCEQ consists of three full-time commissioners appointed by the governor and a professional and administrative staff of over 3,000 employees. Water rights are one of many regulatory responsibilities of the TCEQ. The TCEQ and TWDB interact closely in many of their activities. The TWDB is responsible for developing and updating the State Water Plan and administering an array of financial assistance programs. The TWDB has a governing board of six members appointed by the governor and a staff of about 800 employees.

3.2. Legislatively mandated water management programs

The state-level water allocation systems described in this chapter were created under laws enacted by the Texas Legislature. As discussed later, the statewide water rights permit system for all of Texas except the Rio Grande was implemented pursuant to the Water Rights

Adjudication Act of 1967. The water rights adjudication process mandated by the 1967 Act was completed shortly before a severe statewide drought in 1995-1996 which motivated enactment of the 1997 Senate Bill 1.

The Brown-Lewis Water Management Plan enacted by the Texas Legislature as its 1997 Senate Bill 1 is considered to be a milestone in the history of water resources management in Texas. The designation *Senate Bill 1* is traditionally applied each legislative session to highlight legislation of the upmost importance. The 1997 Senate Bill 1 and subsequent amending legislation authorized the Water Availability Modeling (WAM) System described later in this chapter, a regional and statewide water resources planning process noted below, and other related water management activities.

The 1997 Senate Bill 1 established a program for developing regional water plans that are integrated into a statewide planning process administered by the Texas Water Development Board (TWDB). Committees of local water interests have been established to prepare plans for the orderly development, management, and conservation of the water resources of each of 16 regions. The TWDB provides funding, administrative, and technical support to the regional committees. Consulting firms perform much of the technical work. The 1997 Senate Bill 1 mandated that initial regional plans be completed and incorporated into a statewide plan by 2002. Continuing planning is organized based on updated plans being reported at cycles of not to exceed five years. The 2002, 2007, and 2012 state water plans consists of 16 regional reports and a statewide report which are publically available at the TWDB website.

In evaluating water right permit applications, the TCEQ requires that proposed actions must be consistent with pertinent regional plans. The WAM System is routinely applied in both regional and statewide planning and administration of the water right permit system.

The Texas Instream Flow Program [25] established by Senate Bill 2 (SB-2) enacted by the Texas Legislature in 2001 and expanded by Senate Bill 3 (SB-3) in 2007 is administered jointly by the TCEQ, TWDB, and Texas Parks and Wildlife Department (TPWD). The purpose of the SB-2 program is to perform scientific studies to determine flow conditions necessary for supporting a sound ecological environment in the river basins of Texas. SB-3 mandated a new regulatory approach for protecting environmental flows through a local stakeholder process culminating in rules to be administered through the TCEQ. The objectives of the 2001 SB-2 and 2007 SB-3 are being accomplished largely through the ongoing work of Bay and Basin Expert Science Teams (BBEST) and Bay and Basin Area Stakeholder Committees (BBASC) for the individual river basins, representing the scientific and water management/use communities, with technical support from consultants. The TCEQ, TWDB, and TPWD provides administration oversight and technical support.

Environmental instream flow requirements are determined by the BBEST teams for their assigned streams within a framework of subsistence flows, base flows, high flow pulses, and overbank flood events needed to support riverine ecosystems, wetlands, and freshwater inflows to bays and estuaries. The Stakeholder Committees consider the BBEST recommendations within the content of municipal, industrial, and agricultural water needs as well as environmental water needs. The TCEQ is responsible for final approval and incorporation of the recommendations of these groups and the public into the water rights permit system. As of 2012, the endeavors of the Texas water management community, under the leadership of the three-agency partnership and the BBEST and BBASC groups, to better incorporate environmental considerations into the water rights permit system is well underway and is expected to continue for many years into the future.

3.3. Groundwater management

Most of Texas is underlain by 9 major and 21 minor aquifers that currently supply about half of the water used in the state. Depleting ground water reserves due to excessive pumping is a major problem throughout the state and is forcing a shift from groundwater use to a greater reliance on surface water supplies. Groundwater rights in Texas have historically been based on the common law rule allowing land owners to pump as much water as they wish from under their land. However, increased state regulation of groundwater is evolving over time primarily through the establishment of groundwater conservation districts.

In 1949 and 1985, the Texas Legislature passed laws authorizing creation of groundwater conservation districts with local voter approval. The 1949 legislation allows local residents to petition the state to have a district created. The 1985 amendment authorizes the TCEQ to designate and initiate formation of districts for areas with critical problems. Local voters can still veto a proposed district, but if they do, state funding for water projects can be withheld. Twelve districts existed prior to 1985. As of 2012, 96 groundwater districts covering over half of the land area of the state are operational. Three additional districts are currently in the process of being confirmed by voters through local elections at the county level. A total of 174 of the 254 counties in Texas are within a groundwater conservation district.

The primary purposes of the districts are to encourage water conservation and to protect water quality. Most districts direct their efforts toward prevention of waste, water conservation education, recharge projects, and data collection. Some are now moving toward stricter regulation of groundwater use. The districts tread a narrow path between private ownership of groundwater and state responsibility to protect the water resource. Texans are reluctant to allow anyone to tell them how much water they can pump from under their own land. Governmental regulation of pumping has been driven by necessity as depleting aquifers resulted in major problems. The Harris-Galveston Coastal Subsidence District and Edwards Underground Water Authority have developed the strongest regulatory programs.

The Harris-Galveston Coastal Subsidence District was created in 1957 in response to severe subsidence in the vicinity of the cities of Houston and Galveston. Due to decades of overdrafting groundwater, the ground surface has been lowered over three meters in places in this low-lying, heavily urbanized coastal region. Houston and neighboring smaller cities continue to shift from ground water to surface water supplies. Groundwater pumping is regulated by the Subsidence District through a permit program.

The Edwards Aquifer Authority was created in 1993 largely due to a federal court ruling related to protection of endangered species under the Endangered Species Act. The Edwards is a limestone aquifer shared by San Antonio, several smaller cities, and extensive irrigated farming interests. San Antonio is the largest city in the U.S. that relies solely on groundwater for its water supply. Springs fed by the Edwards Aquifer maintain the flow of several rivers and support ecosystems that include several endangered species. The Edwards Aquifer Authority administers a water rights permitting system to facilitate aquifer management. Pumping limits are reduced whenever water levels in selected wells fall below specified criteria.

All of the groundwater conservation districts are required to develop, implement, and periodically update management plans for the effective management of their groundwater resources. These plans are subject to approval by the TWDB and are publically accessible through the TWDB website.

Although interstate and international aquifers are important, allocation agreements do not exist. The U.S. and Mexico have different legal reasons for their lack of management of ground water [26]. The Mexican federal government has the authority to enforce comprehensive management and regulation of ground water but has not chosen to do so. In the U.S., the legal framework is inadequate and chaotic. Another constraint to joint U.S. and Mexico management of ground water is the lack of clarity of international ground water law [26].

3.4. Allocation of the waters of the Rio Grande

The Rio Grande (Spanish for Large River) is unique relative to the other river basins of Texas from several perspectives. It is shared by two nations. The Lower Rio Grande Valley accounts for the majority of the surface water irrigation in Texas. The intensive agricultural production of the region depends almost exclusively on the Rio Grande with little use of groundwater. Other major irrigation regions of the state rely primarily on groundwater. The water rights system for the Lower Rio Grande was developed separately and has distinct differences from the remainder of the state, particularly in regard to the priority system and water master operations. Fort Quitman shown in Fig. 3, located 140 km downstream of the city of El Paso, is used as the divide between the lower and upper portions of the basin in both the international and state water allocation systems.

The Rio Grande Basin is shared by Mexico and three states in the U.S. Water allocation is governed by two international treaties and two interstate compacts. Allocation of the Texas share of the waters of the Rio Grande to irrigators, cities, and other users is based on a water rights permit system governed by state law. The Rio Grande Compact approved by the legislatures of Colorado, New Mexico, and Texas in 1939 allocates the uncommitted waters of the Rio Grande above Fort Quitman. The Pecos River Compact adopted in 1948 allocates the waters of that tributary between Texas and New Mexico.

3.4.1. Mexico-United States treaties

A 1906 treaty between the U.S. and Mexico provides for delivery of 74 million m^3/yr of Rio Grande water to Mexico in the El Paso-Juarez Valley above Fort Quitman. Elephant Butte Reservoir in New Mexico, operated by the Bureau of Reclamation, and the American and

International diversion dams near El Paso, operated by the IBWC are used to implement the water allocation provisions of the treaty. The treaty further provides that if water is unavailable, the amount allocated to Mexico shall be diminished in the same proportion as water delivered to irrigate lands in the United States. This provision has been invoked in about a third of the years since 1951.

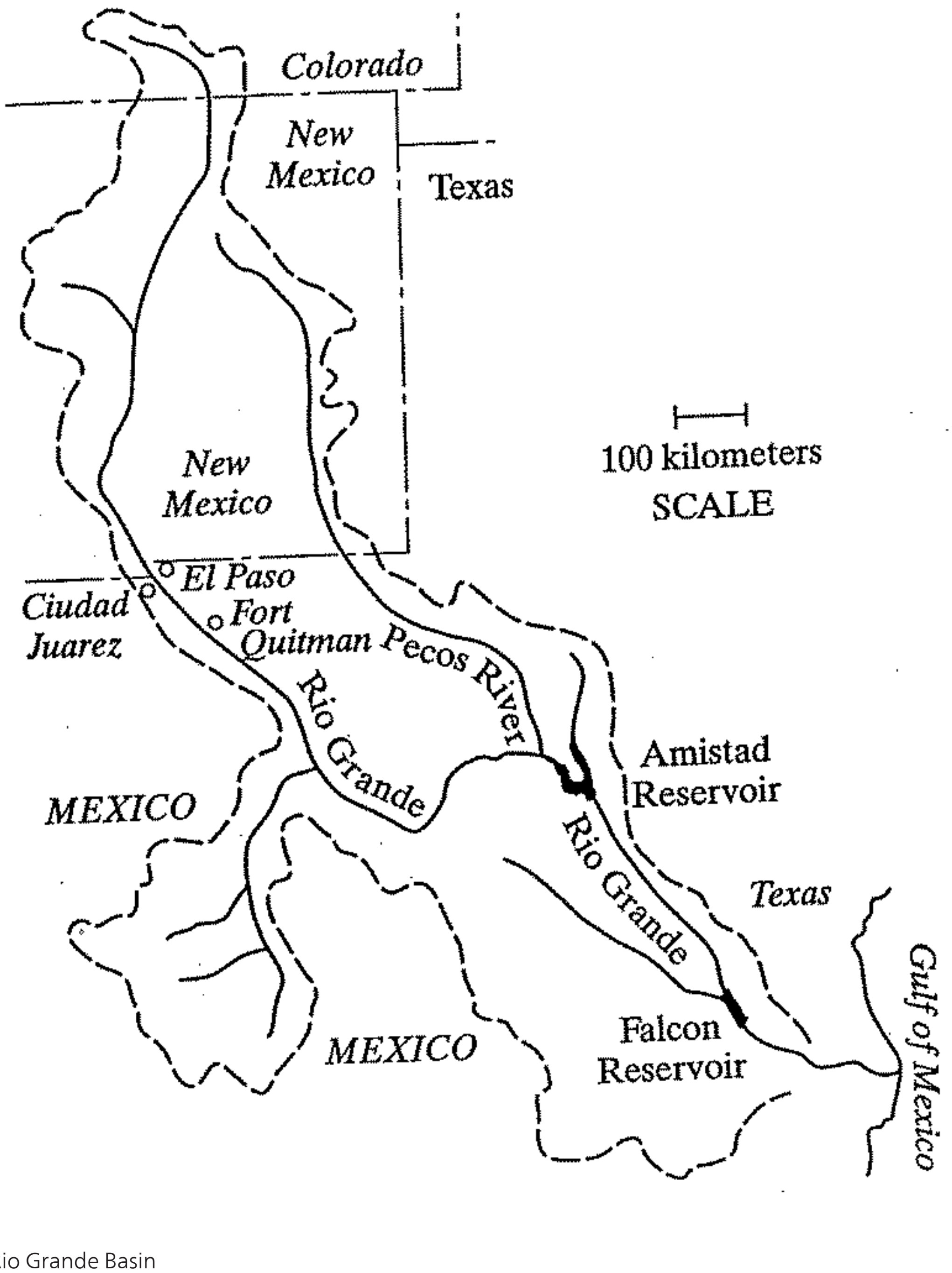

Figure 3. Rio Grande Basin

The Water Treaty of 1944 expanded the International Boundary Commission to the International Boundary and Water Commission (IBWC), provided for the distribution of waters of the Rio Grande from Fort Quitman to the Gulf of Mexico between the two nations, and authorized construction of International Amistad and Falcon Reservoirs.

The 1944 treaty administered by the IBWC also includes provisions for allocation of the waters of the Colorado River. The Colorado River drains 629,000 km^2 in seven western states and flows into the Gulf of California in Mexico. Although both are included in the same 1944 treaty, water allocation for the Colorado River and Rio Grande are very different. The Rio Grande serves as a boundary between the two countries. The Colorado River flows from the U.S. to Mexico with most of its watershed area being located in the U.S.

The IBWC is composed of a Mexico Section with commissioner and technical and administrative staff located in Ciudad Juarez and a U.S. Section with offices across the river in El Paso. Amistad and Falcon Reservoirs are operated by the IBWC primarily for flood control and water supply for the Lower Rio Grande Valley. Hydroelectric power generation uses releases for downstream water supply. The U.S. share of the conservation storage is used to meet demands in the lower basin in accordance with the state water rights system.

Conservation and flood control capacities are 4.17 billion m^3 and 2.15 billion m^3 in Amistad Reservoir and 3.29 and 0.63 billion m^3 Falcon Reservoir. In accordance with the 1944 treaty, the U.S. has 56.2% and 58.6% of the conservation storage capacity of Amistad and Falcon, respectively, with Mexico owning the remainder. The IBWC operates Anzaldus and Retamal Dams on the lower Rio Grande to facilitate diversions. The travel time for releases from Falcon Reservoir to reach the most downstream diversion locations is about a week.

The IBWC maintains a continuous accounting of the volume of stored water owned by each of the two countries. Stream flows into Falcon and Amistad Reservoirs are allocated between the two countries. Flows on a number of major tributaries named in the treaty are gauged and allocated as specified by the treaty. All other flows not otherwise allocated are divided equally between the two countries. Mexico receives all the flows from several specified Mexican tributaries and two-thirds of the flows from other specified tributaries. The U.S. receives all the flows from certain U.S. tributaries and one-third of the flows from the other specified tributaries. Computations are performed routinely to allocate the reservoir inflow and evaporation volumes, which are combined with recorded releases to determine the amount of water that each country has in storage.

The 1944 treaty gives the U.S. a right to one-third of the flow reaching the Rio Grande from six Mexican tributaries, provided that this third shall not be less, as an average amount in cycles of five consecutive years, than 431,721,000 m^3 annually. Other provisions relate to special conditions. A significant deficit accumulated over several years during the 1900's-2000's in meeting these requirements. Discussions addressing the stream flow deficit owed by Mexico to the U.S. included requests by the U.S. that operating policies for reservoirs in Mexico be modified to mitigate the deficit.

3.4.2. Allocation of the Texas share of the lower Rio Grande

The Texas share of the waters of the Rio Grande below Fort Quitman was allocated among numerous water rights holders in conjunction with a massive lawsuit, commonly called the

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Lower Rio Grande Valley Water Case. The lawsuit was filed in 1956, the trial was held in 1964-1966, and the final judgment of the appellate court was filed in 1969. In 1971, the Texas Water Rights Commission adopted rules and regulations implementing the court decision. Assorted versions of riparian and appropriative rights were combined into a permit system. The litigants in the Rio Grande law suit included 42 water districts and 2,500 individuals. More than 90 lawyers appeared before the court. The expense and effort demonstrated the impracticality of a purely judicial determination of water rights for the entire state and led to enactment of the Water Rights Adjudication Act of 1967.

The lawsuit resulted in water rights being divided into three categories. Municipal rights have the highest priority. Irrigation rights are divided into Class A and Class B rights, with Class A rights receiving more storage in Falcon and Amistad Reservoirs storage accounts in the allocation procedure. Although this weighted priority system for irrigation rights has little significance during years of plentiful water, its effect in water-short years is to distribute the shortage among all users, with the greater shortages occurring on lands with Class B water rights.

Most of the U.S. share of the water regulated by Amistad and Falcon Reservoirs is used in the very productive agricultural region of Texas below Falcon Reservoir. Irrigation districts, individual farmers, and cities communicate their water needs to the TCEQ Rio Grande Water Master Office, which in turn schedules releases from Falcon and Amistad Reservoirs with the IBWC. The Water Master Office maintains an accounting of the amount of water used and the amount of water in reservoir storage allocated to each of about 1,600 water rights accounts.

The allocation rules administered by the TCEQ Water Master first provide a reserve of 278 million m^3 in Amistad and Falcon Reservoirs for domestic, municipal, and industrial uses. Next, available water is allocated to an operating reserve that provides for seepage and evaporation losses, adjustments required as the IBWC computations of Mexico-U.S allocations are updated periodically, and emergency requirements. The remaining water in storage is allocated among all the irrigation permit holders. The storage is basically allocated in proportion to annual diversion rights, except the Class A rights are multiplied by a factor of 1.7 to allow them a greater storage allocation than Class B rights. Other provisions include limiting each storage allotment to not exceed more than 1.41 times its authorized diversion right. If an irrigation right does not use water for two consecutive years, its storage account is reduced to zero.

3.5. Interstate river compacts

Texas participates in five interstate river compacts executed by the member states and approved by the U.S. Congress. The rivers and the dates the compacts became effective are Rio Grande, 1939, Pecos, 1948, Canadian, 1952, Sabine, 1954, and Red, 1980. The purposes of the compacts are to provide for equitable allocation of water between the states and to facilitate cooperative planning and management. Commissions with a representative from each member state administer the compacts. The commissioners have minimal staffs and rely on the state water agencies for technical support.

Texas filed a lawsuit against New Mexico in 1974, claiming that Texas did not receive its full share of water allocated by the 1948 Pecos River Compact due to over-use in New Mexico [27]. In 1988, based on the recommendations of a court appointed Special Master, the Supreme Court awarded Texas a cash settlement for past damages and established a Pecos River Master to administer future water allocations under the compact.

3.6. Statewide surface water rights permit system

All of Texas except the Lower Rio Grande below Fort Quitman has a consistent surface water rights permit system which is different than the system just described for the Lower Rio Grande. The TCEQ administers both systems. River authorities, municipal utility districts, cities, irrigation districts, farmers, companies, and citizens hold about 8,000 permits statewide. The water is owned by the state, with rights granted to organizations and people to use prescribed amounts for prescribed purposes under prescribed conditions.

3.6.1. Historical evolution of water rights

The riparian doctrine was introduced in Texas during the rule of Spain and later Mexico and after independence in 1836, in a somewhat different form by the Republic of Texas. In 1840, the state of Texas adopted the common law of England with another variation of riparian water rights. The extent to which riparian rights allow large irrigation developments or other large amounts of use depends upon the laws in effect when the land was originally transferred from public to private ownership. Riparian rights are different depending on whether the land can be traced to land grants from Spain, Mexico, Republic of Texas, or the state of Texas.

The prior appropriation doctrine was adopted by legislative acts in 1889 and 1895. After 1895, public lands which transferred into private ownership no longer carried riparian water rights. Land already privately owned kept its riparian rights. At first, appropriation simply involved water users filing sworn statements with county clerks describing their use. Since 1913, more strictly administered procedures have been followed based on a statewide appropriation system administered by a centralized state agency.

All appropriation statutes recognized existing riparian rights. Riparian landowners could also acquire appropriative water rights. In 1926, the courts divided stream flow into *ordinary normal flow* and *flood flow*. Riparian rights were limited to normal flow and therefore are not applicable to flood waters impounded by reservoirs. Although difficult to apply in actual practice, this distinction was the basis for correlating riparian and appropriative rights from 1926 until the riparian rights were merged into the appropriative system pursuant to the Water Rights Adjudication Act of 1967.

Thus, an unmanageable system evolved, with various conflicting rights and many rights being unrecorded. The 1951-1957 drought motivated the previously noted Lower Rio Grande Valley Water Case which clearly demonstrated the impracticality of a purely judicial adjudication of water rights statewide. Thus, the Water Rights Adjudication Act was enacted by the Texas legislature in 1967, with the stated purpose being to require a recording of all

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claims for water rights, to limit the exercise of those claims to actual use, and to provide for the adjudication and administration of water rights. All riparian water rights were merged into the prior appropriation system, creating the present permit system applicable to all of Texas except the Lower Rio Grande. The water rights adjudication process required for transition to the permit system was initiated in 1968 and completed by the late 1980's.

3.6.2. Prior appropriation permit system

Water rights are granted by a state license, or permit, which allows the holder to divert a specified amount of water annually at a specific location, for a specific purpose, and to store water in reservoirs of specified capacity. Any organization or person may submit an application to the TCEQ for a new water right or to change an existing water right at any time. The TCEQ will approve the permit application if unappropriated water is available, a beneficial use of the water is contemplated, water conservation will be practiced, existing water rights are not impaired, and the water use is not detrimental to the public welfare. Proposed actions reflected in water right permit applications must be consistent with regional water plans.

The water authorized to be appropriated under the terms of the particular permit is not subject to further appropriation unless the permit is canceled. A permit may be canceled if water is not used during a 10-year period. Special term permits may also be issued allowing water use for specified periods of time. The Rio Grande and segments of other rivers are over-appropriated with no new rights for additional water use being granted. However, unappropriated water is still available for appropriation in other regions of the state.

A permit holder has no actual title of ownership of the water but only a right to use the water. However, a water right can be sold, leased, or transferred to another person. The Lower Rio Grande Valley has been the only region of Texas with an active water market historically. In 1993, the legislature established a statewide water bank to be administered by the TWDB. Although transfers can be accomplished independently of the water bank, the program was created to encourage and facilitate water marketing, transfer, and reallocation.

The Texas Water Code lists beneficial uses in order of priority as follows: (1) domestic and municipal, (2) industrial, (3) irrigation, (4) mining, (5) hydroelectric, (6) navigation, (7) recreation and pleasure, and (8) other beneficial uses. These priorities are invoked only when a conflict exists between water use applications. Under the prior appropriation system, after a permit is in effect, priorities are based on the date specified in the permits. During the 1968-1980's adjudication process, priority dates were established based on historical water use. Since then, priorities are based on the dates that the permits are issued. In times of emergency, cities may take water even if non-municipal users are adversely affected, regardless of priority dates.

4. Water Rights Analysis Package (WRAP) modeling system

The Water Rights Analysis Package (WRAP) computer modeling system is generalized for application to river/reservoir/use systems located anywhere in the world, with model-users developing input datasets for the particular river basin of concern. For applications in Texas, publicly available WRAP input datasets from the TCEQ Water Availability Modeling (WAM) System [28] are altered as appropriate to reflect proposed water management plans of interest, which could involve changes in water use or reservoir/river system operating practices, construction of new facilities, or other water management strategies.

WRAP simulates water resources development, management, regulation, and use in a river basin or multiple-basin region under a priority-based water allocation system. In WRAP terminology, a water right is a set of water use requirements, reservoir storage and conveyance facilities, hydropower projects, operating rules, and institutional arrangements for managing water resources. Stream flow and reservoir storage is allocated among users based on specified priorities, which can be defined in various ways. Simulation results are organized in optional formats including time sequences of many different variables, summaries, water budgets, frequency relationships, and various types of reliability indices.

The public domain WRAP software and documentation [29, 30, 31, 32, 33] may be downloaded free-of-charge from http://ceprofs.tamu.edu/rwurbs/wrap.htm. The WRAP website links to TCEQ WAM and TWRI websites that provide reports, datasets, and other related information. Wurbs provides a concise summary of WRAP [34] and comparison with other generalized modeling systems [35].

WRAP modeling capabilities that have been routinely applied in the Texas WAM System consist of using a hydrologic period-of-analysis of about 60 years and monthly time step to perform water availability and reliability analyses for municipal, industrial, and agricultural water supply, environmental instream flow, hydroelectric power generation, and reservoir storage requirements. Recently developed additional WRAP modeling capabilities include: short-term conditional reliability modeling [36]; daily time step modeling capabilities that include flow forecasting and routing and disaggregation of monthly flows to daily; simulation of flood control reservoir system operations [31]; and salinity simulation [37]. Further improvements to WRAP currently underway, as of 2012, are focused on better integrating environmental flow requirements into comprehensive water management.

The generalized WRAP modeling system was developed and continues to be expanded at Texas A&M University (TAMU). Early versions dating back to the 1980's were developed under the sponsorship of the Texas Water Resources Institute (TWRI) and U.S. Department of Interior. Efforts at TAMU to expand and improve WRAP from 1996 through the present have been sponsored primarily by the TCEQ. However, the TWDB, U.S. Army Corps of Engineers, Brazos River Authority, and other agencies have funded specific improvements to WRAP. Model development has been an evolutionary process with extensive interactions between professionals from the agencies and consulting firms applying the model to specific river basins and university researchers responsible for improving the modeling methodology and computer software.

4.1. Texas water availability modeling system

As previously noted, water management legislation known as Senate Bill 1 enacted by the Texas legislature in 1997 directed the water agencies to establish a regional planning process and a water availability modeling system. The Texas WAM System was implemented by the TCEQ, its partner agencies (TWDB and TPWD) and contractors (ten consulting engineering firms and two university research entities) during 1997-2002 pursuant to the 1997 Senate Bill 1. The WAM System has continuously to be improved and expanded since 2002 along with being routinely applied by the water management community [28].

The Water Availability Modeling (WAM) System consists of the generalized WRAP and input datasets for the 23 river basins of Texas. The WAM datasets include naturalized stream flows at a total of about 500 gauged sites, watershed parameters for distributing these flows to over 12,000 ungauged locations, 3,450 reservoirs, various other constructed infrastructure, operating plans that in many cases are quite complex, two international treaties, five interstate compacts, various contractual agreements, and water use requirements associated with about 8,000 water right permits reflecting two different water right systems.

Prior to creation of the WAM System, many water right permit holders incorrectly assumed that the amount of water specified in their permits would always be available to them. Senate Bill 1 required that the TCEQ notify all permit holders regarding the reliabilities associated with their permits. All water needs cannot be met during severe droughts.

The TCEQ requires that permit applicants, or their consultants, apply the WRAP/WAM system to assess supply reliabilities and flow and storage frequencies associated with their proposed actions and the impacts on all of the water users in the river basin. TCEQ staff applies the modeling system to evaluate the permit applications. The TWDB and regional planning groups apply the modeling system in their planning studies. The TCEQ requires that water right permit applications be consistent with regional plans. River authorities and other water suppliers apply the modeling system in operational planning studies.

4.2. Lessons learned in implementing the WRAP/WAM system

Developing and applying computer models have typically been viewed in terms of the engineering and scientific concepts and methods incorporated in the models. However, modeling has important institutional as well as technical dimensions. Lessons learned from development and application of the Texas WAM System demonstrate the importance of the following two institutional dimensions of river/reservoir system modeling.

1. Modeling water rights, contractual agreements, treaties, interstate compacts, and other complex institutional aspects of water resources development, management, allocation, and use may be a key consideration in developing and applying a modeling system.

2. Effective implementation of a modeling system may require a partnership effort of an entire water management community that includes water users, political officials, legislatures, environmental and other non-governmental special interest groups, government agencies, consulting firms, and university researchers.

The following general observations characterize the Texas experience in implementing a water availability modeling system.

- Droughts motivate political concern, improvements in water management, and development of computer modeling systems.
- Partnerships and consensus building are key aspects of water resources planning and management. Likewise, a water management community may work together to effectively implement a shared modeling system. Model development and application may be an institutional partnership effort.
- Administration of water allocation systems has become a central focus of river basin management. Regulatory and planning functions are integrally related. Shared modeling tools can facilitate integration of planning and regulatory functions.
- Modeling systems include computer programs, databases, organizations, people, and decision-making processes. Compilation and management of voluminous data is a central governing concern. A modeling system is constructed rather than just a model.
- Model development is a dynamic evolutionary process. As long as a computer simulation model such as WRAP continues to be applied, its development is never completed. Model development is a process of continual expanding and improving.
- Water availability modeling is essential for effective water management.

5. Water allocation issues

Allocating water resources that are highly variable both temporally and spatially among a myriad of water management entities and numerous water users within an institutional setting that has evolved historically over many years is necessarily complex. The following concerns highlighted by the Texas experience are illustrative of the numerous complexities in creating and administering water allocation systems.

For most of Texas, the water right permit system is administered without water master operations. Upon request, the TCEQ takes enforcement action to stop reported unauthorized water use in violation of water rights permits. However, water users are not closely monitored except during droughts or emergency conditions. This approach is similar to most western states. Several western states have water-master operations, but most states do not. The TCEQ during 2012-2013 is investigating the feasibility of expanding water master operations in Texas.

The TCEQ Lower Rio Grande Water Master Office maintains a precise accounting of water use, working closely with irrigators, cities, and the International Boundary and Water Commission. With completion of the adjudication process during the late 1980's, plans were developed to establish water-master operations in all of the major river basins of Texas. The South Texas Water-Master Program was created in the late 1980's with responsibilities for

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the Guadalupe, Nueces, and San Antonio River Basins. However, water users are reluctant to have requirements imposed upon them for installing meters and monitoring and regulating diversions. Political pressures have prevented the establishment of water-master offices in other river basins. However, the Texas Legislature in 2012 directed the TCEQ to solicit public input and develop recommendations for establishing water master operations for other river basins.

Since stream flow, evaporation, reservoir sedimentation, water use, and other factors are highly variable, and the future is unknown, water availability must be viewed from a reliability, likelihood, or percent-of-time perspective. Tradeoffs occur between the amount of water to commit for beneficial use and the level of reliability that can be achieved. Beneficial use of water is based on assuring a high level of reliability. However, if water commitments are limited as required to assure an extremely high level of reliability, the amount of stream flow available for beneficial use is constrained, and a greater proportion of the water flows to the ocean or is lost through reservoir evaporation. The optimal level of reliability varies with type of water use. Water allocation decisions necessarily require qualitative judgment in determining acceptable levels of reliability both in terms of the reliability of the proposed new or increased water use and the impacts on the reliabilities of all of the existing water users.

Many of the existing water rights adjudicated pursuant to the 1967 Water Rights Adjudication Act and the Lower Rio Grande Court Case as well as some recently established rights have supply reliabilities that are much lower than the water management community considers desirable. However, the TCEQ has applied more stringent criteria in approving newer water right permits or modifications to permits. In evaluating water right permit applications for agricultural irrigation, the TCEQ now applies the criterion that at least 75 percent of the proposed demand should be supplied at least 75 percent of the time as determined by the WRAP/WAM System. The TCEQ criterion for municipal permit applications is that 100 permit of the demand should be supplied 100 permit of the time based on the premises reflected in the WRAP/WAM model including historical hydrology. However, these criteria may be modified depending upon backup water supply sources. For example, with depleting groundwater reserves, a transition to a surface water source may be worthwhile, even if the reliability of the surface water source is low, if groundwater can still be used as a backup supply.

Although Texas and other western states are viewed as adopting the prior appropriation doctrine, strictly speaking a pure prior appropriation system is not feasible and does not exist. Although the effect may be very small, developing additional supplies for new users always affects downstream supplies. Also, in drought situations, water supply shortages are shared, to some degree, by water users regardless of the relative seniority of their rights. Sharing of water during drought typically depends on political negotiations, alternative demand management and supply augmentation measures available to different entities, and other factors in addition to the water rights permit system.

Assigning water right priorities to maintaining reservoir storage levels relative to diversion rights is another issue. Protecting reservoir inflows is crucial to providing a dependable water supply. Each drawdown could potentially be the beginning of a several-year drawdown that empties the reservoir. However, forcing appropriators, with rights junior to the rights of the reservoir owner, to curtail diversions to maintain inflows to an almost full, or even an almost empty, reservoir is difficult and often is not the optimal use of the water resource. If junior diversions are not curtailed, the reservoir will likely later refill anyway, without any supply shortages occurring. Handling of the storage aspect of water rights is not yet precisely defined in Texas except for the Lower Rio Grande. The Lower Rio Grande is simpler in this regard because essentially all of the water users are supplied by two large reservoirs. Elsewhere, numerous reservoirs are owned and operated by various entities in the same river basin.

Although some recently issued permits specify the amount of the diversion to be returned to the stream, most permits do not. Return flows can significantly impact the availability of water to downstream users. This issue is currently being addressed particularly as related to programs to encourage reuse of wastewater effluents.

From the perspective of hydrology and water resources management, groundwater and surface water are closely interrelated. Use of one resource often has significant impacts on the other. However, there is only limited governmental control over the use of groundwater in Texas. Consequently, conjunctive management of ground and surface water resources is difficult. Depleting groundwater reserves are forcing a shift toward greater groundwater regulation.

Water availability depends upon water quality as well as quantity. The water supply capabilities of several major river systems that include very large reservoirs in Texas and neighboring states are severely constrained by salinity originating from natural salt deposits in geologic formations underlying the upper watersheds of the rivers. Salinity simulation capabilities have been added to WRAP for assessing the impacts of salinity on water availability [37]. Salinity problems are addressed in the regional plans [24]. However, incorporation of salinity into the water allocation systems is a complex issue yet to be resolved.

The Texas Water Code has required consideration of environmental flow needs in the water rights permitting process since 1985. Such needs include maintenance of aquatic habitat and species, water quality, public recreation, wetlands, and freshwater inflows to bays and estuaries. Although such needs have been considered in issuing permits since 1985, most water rights in the state have been granted without specifying instream flow requirements. Under mandates enacted by the Texas Legislature in 2001 and 2007, developing methodologies for establishing environmental flow criteria, establishing requirements for each river reach in the state, and incorporating them into the water rights system is currently a major focus.

6. Summary and conclusions

As water demands increase with population and economic growth, water allocation systems become increasing important worldwide. This chapter illustrates mechanisms for allocating water and highlights issues that must be addressed in their implementation. The Texas experience illustrates fundamental principles, issues, strategies, and complexities involved in developing and administering water allocation systems. Allocation of water resources among nations, states, regions, types of use, and numerous water users is a governing concern in water management in Texas as well as throughout the world.

Water allocation practices in Texas have evolved historically over centuries, with significant improvements occurring in recent years that continue to be refined. Texas shares water with Mexico and several neighboring states in the United States. Thousands of government agencies, cities, private companies, and citizens within Texas hold rights to use the waters of the state. Legal rights to use surface water differ from those for ground water. Surface water allocation for the Lower Rio Grande is different than for the rest of the state. With growing demands on limited water resources, expanding and refining water allocation systems has become a central governing concern in water management. The following observations regarding development and administration of water allocation systems in Texas are generally applicable in various other regions throughout the world.

- Water allocation systems include hierarchical systems of treaties and compacts between nations and states, ground water rights systems, surface water right systems, reservoir project ownership and operating practices, and contracts and agreements among a myriad of water management entities and water users. These water allocation mechanisms are overlapping and interconnected. Water allocation is integrally connected with other water resources planning and management activities.

- Water allocation practices evolve historically. In Texas, with growing demands on limited water resources, by the 1950's a disorganized myriad of water allocation practices had become a governing constraint to effective water management. Major change involving better water allocation mechanisms was necessary. The evolution of water allocation systems is continuing now and will continue in the future.

- Droughts motivate political action to improve water allocation systems. In Texas, major droughts led to milestone water management legislation being enacted in 1967 and 1997. The current drought that began in 2010 is expected to motivate additional legislative action that will contribute to the continued evolution of water allocation systems.

- The historical competition between agricultural, municipal, industrial, energy, and environmental water uses continues. There is a continuing shift from agricultural to municipal water use. Establishing and implementing environmental instream flow requirements is currently a major focus in Texas.

- Capabilities for assessing water availability and supply reliability within the framework of governing water allocation systems are essential for effective water resources planning and management. The Water Rights Analysis Package (WRAP) modeling system significantly contributes to effective water planning and allocation in Texas. WRAP is generalized for application to river/reservoir systems located anyplace in the world.

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